ILD calorimetry: a review

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on behalf of the ILD calorimeter groups

ILD meeting,
Instytut Fizyki Jądrowej PAN, Kraków
24th September 2013

Advertisement

http://www.icepp.s.u-tokyo.ac.jp/lcws13/

Early registration (11.11% saving !!)
deadline 15 October

This talk will be a general overview

many more details will come in later talks

Charged particles' momenta excellently measured in TPC

Calorimetry must measure neutral particles' energies

No strong physics requirement to measure
individual neutral particles
with excellent precision

Precise measurement hadronic jet energy allows
full use of dominant hadronic W, Z, H decay modes
maximised use of ILC collisions
improved measurement precision @ fixed $\int\mathcal{L}$
reduced $\int\mathcal{L}$, running time, ILCU, JPY, $, € @ fixed precision

Jet Energy Resolution

benchmark : separation of hadronic decays of W and Z
- jet energy resolution of 3~4% is good
  - (similar contribution as natural widths)
  - (better is of course better...)

Particle Flow reconstruction generally accepted as the
- most promising way to meet this requirement
  - also applicable to reconstruction of e.g. τ decay modes
- requires high segmentation
  - ~5x5 mm^2 (ECAL), 1x1~3x3cm^2 (HCAL)

Also essential for good Jet Energy Resolution:
- Calorimeters as hermetic as possible
  - No projective cracks (for ECAL)
- Very low mass tracker
  - (in particular in terms of hadronic interactions)

The high channel densities required,
and the need to constrain dead material due to detector services

imply

extreme integration of front-end electronics
low power dissipation

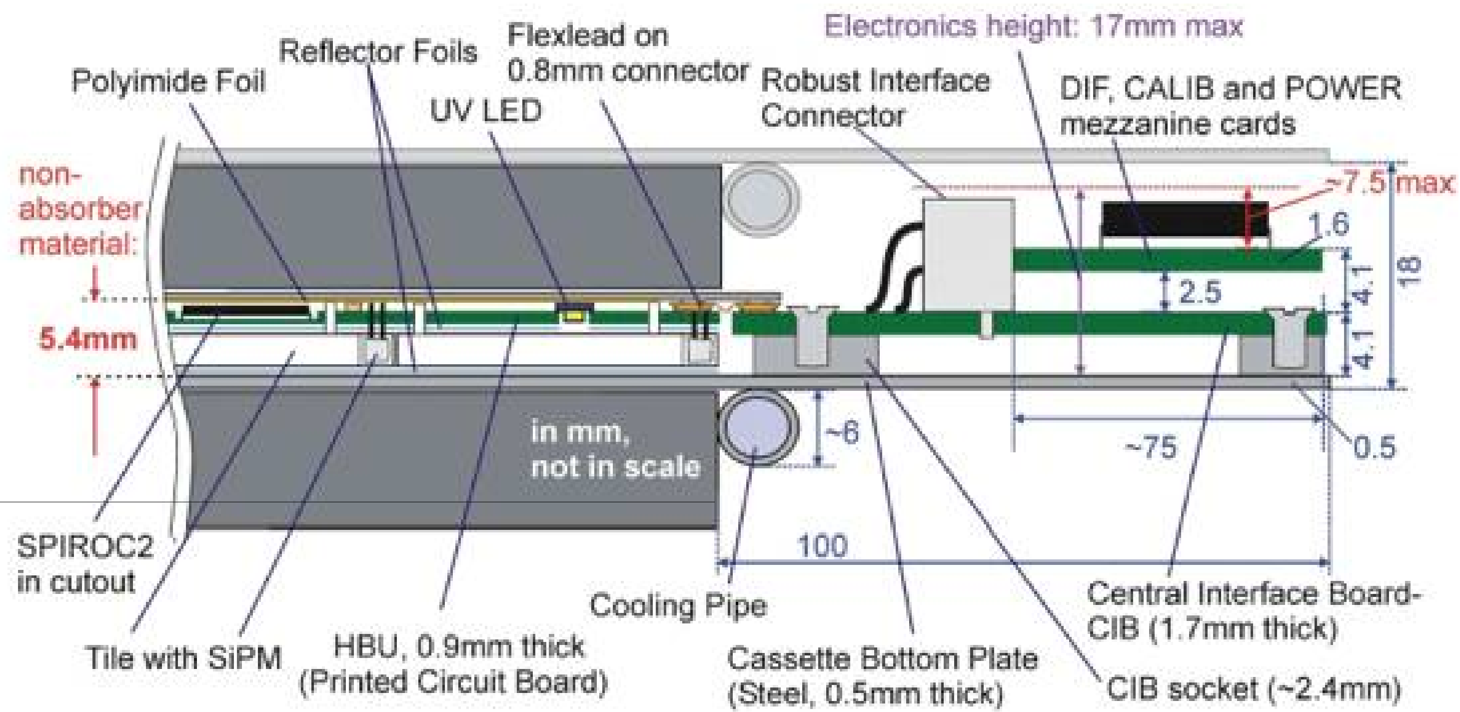
FE electronics distributed within detector volume

power-pulsing of these FE electronics

e.g. **AHCAL**:
scintillator, SiPM,
calibration system,
FE electronics
in 5.4 mm

~0.1m of interface cards
services >2 m detectors

2.2 m



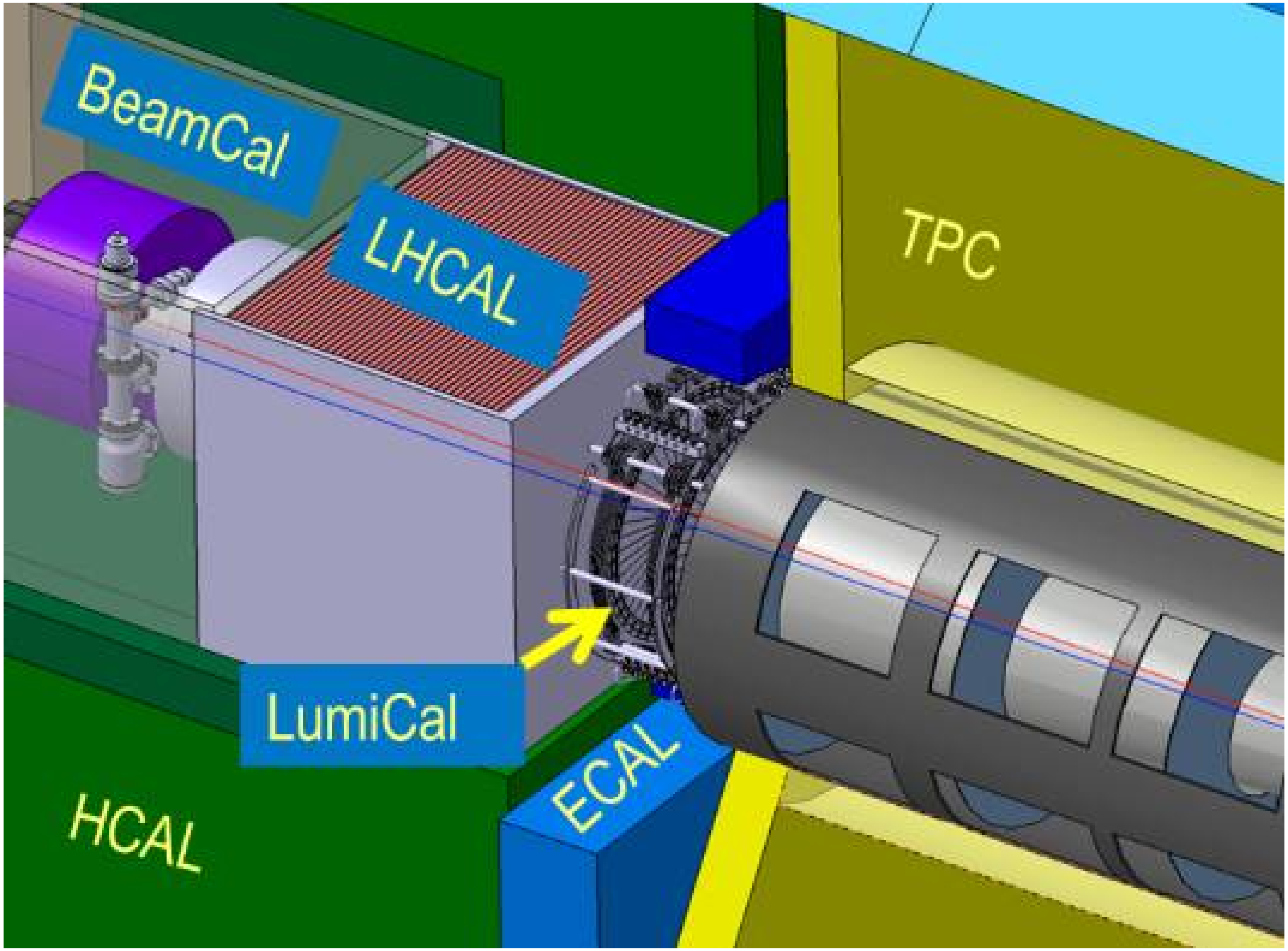
Forward region

Calorimeters with specific roles and requirements

- LumiCal
  - Measurement of integrated via Bhabha scattering
- BeamCal
  - beam parameter measurement via pair production
    - bunch-by-bunch luminosity
    - fast machine feedback
- LHCAL
  - Extend HCAL coverage

Highly segmented, radiation tolerance detectors required

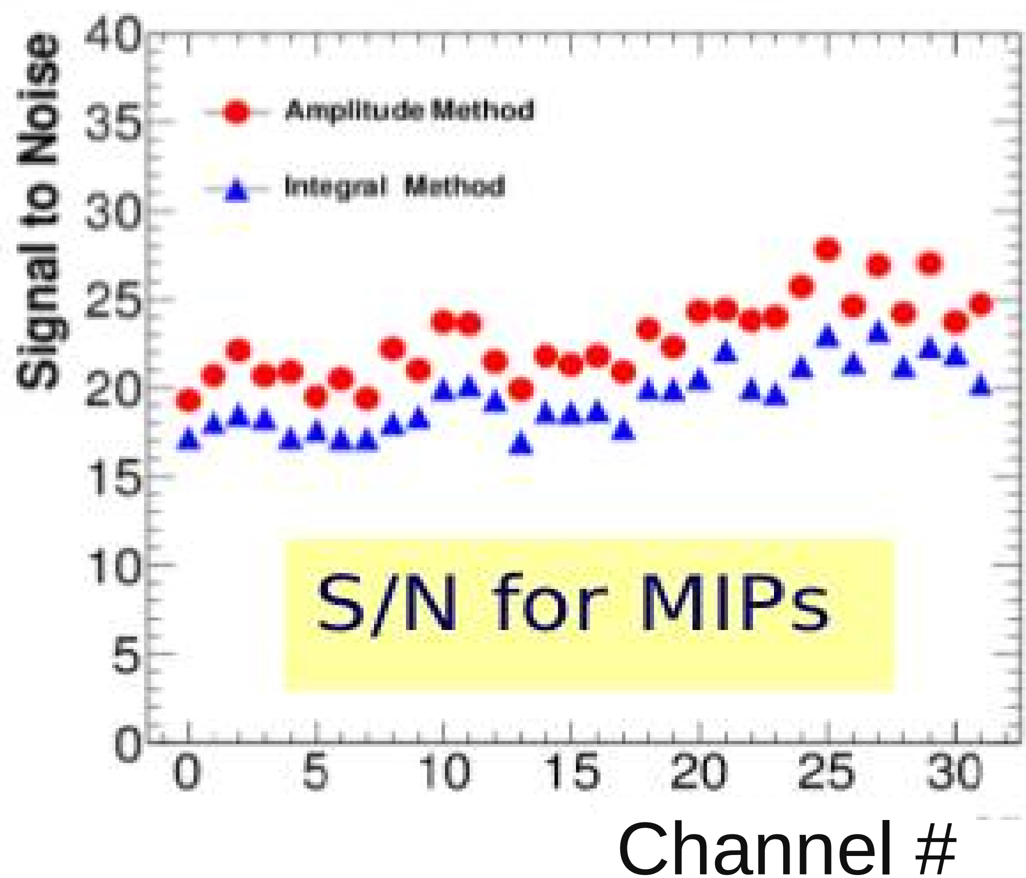
Developed in FCAL collaboration


BeamCal
LHCAL
TPC
LumiCal
ECAL
HCAL

BeamCal and LumiCal

Suitable sensors (GaAs, Si) developed together with dedicated readout ASICs

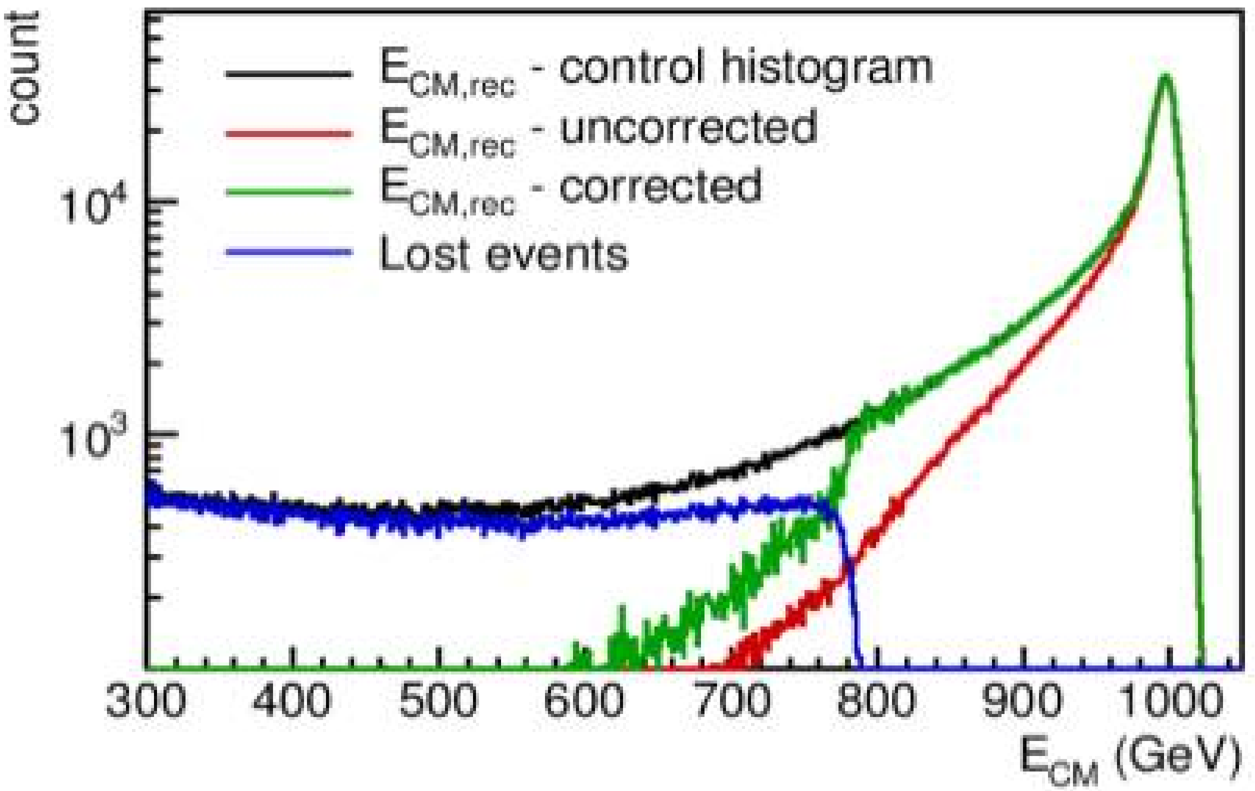
Beam tests performed, including high radiation tests



Precise detector alignment particularly important for FCALs

Dedicated efforts to develop laser-based system

Simulation studies of Luminosity measurement precision



e.g. correction of beam-beam effects (CM frame != lab frame) in lumi measurement

LHCAL seems rather forgotten...

If ILD really needs an LHCAL (?), this is rather critical

ECAL & HCAL

Fortunate to have several contrasting technological options
for both ECAL and HCAL
developed by groups who are “forced” to
talk to one another in CALICE

<u>ECAL</u>
Silicon PIN diodes
Scintillator strips (1x4 cm^2), PPD readout (PPD = SiPM, MPPC, ...)

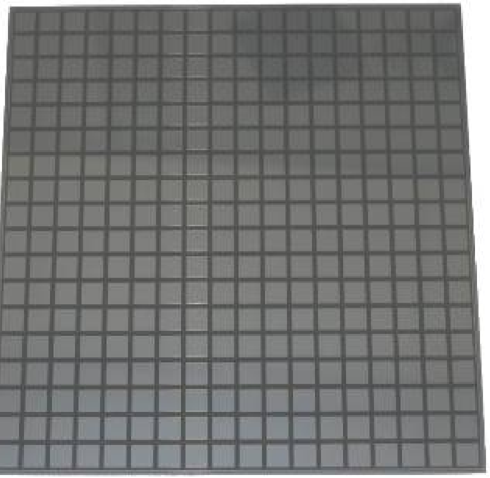
(Si-Sc hybrid)
(MAPS)

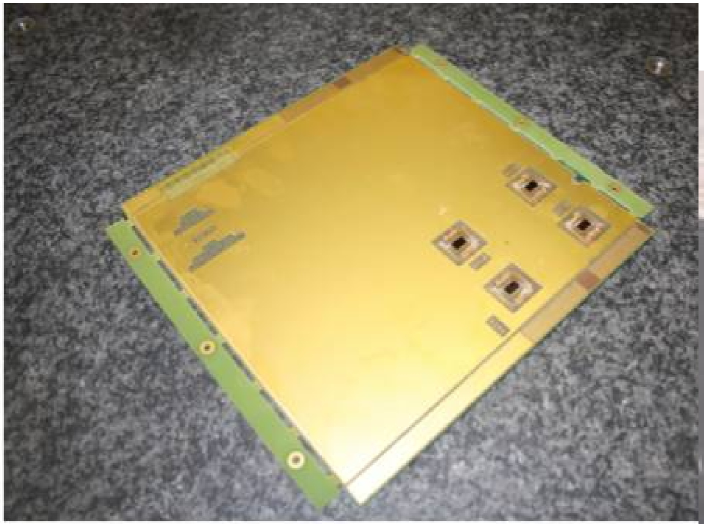
<u>HCAL</u>
Scintillator tiles (3x3 cm^2 tiles), PPD readout
Gas-based:
glass RPC with semi-digital readout
(Micromegas)

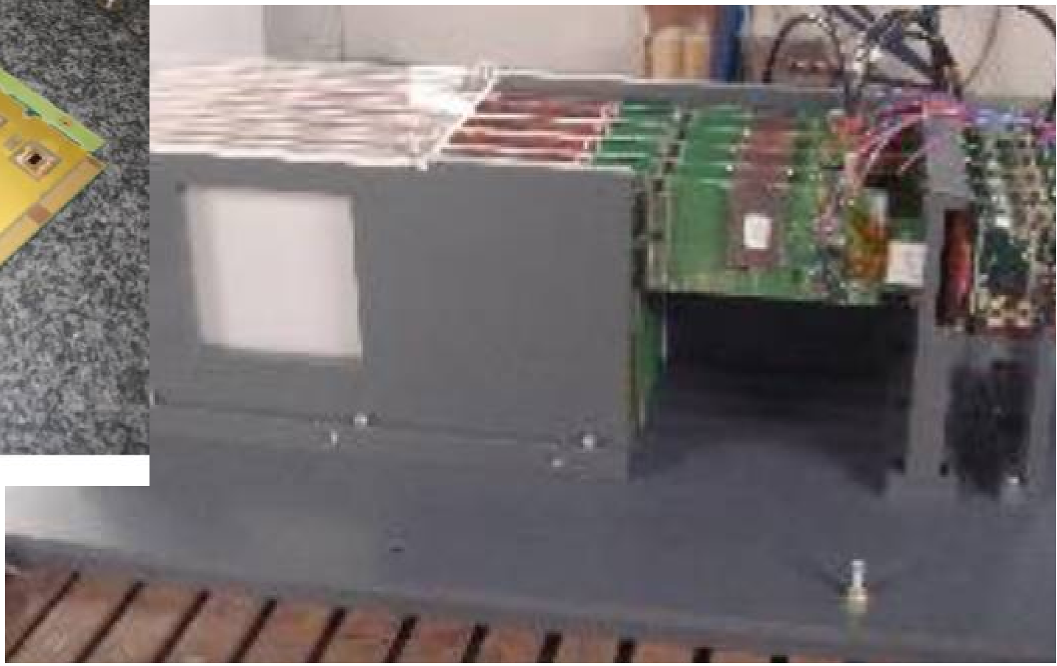
Common aspects (at least in principle):
FE electronics (digital part), DAQ architecture

Very close synergies between 2 scintillator designs

Technical aspects



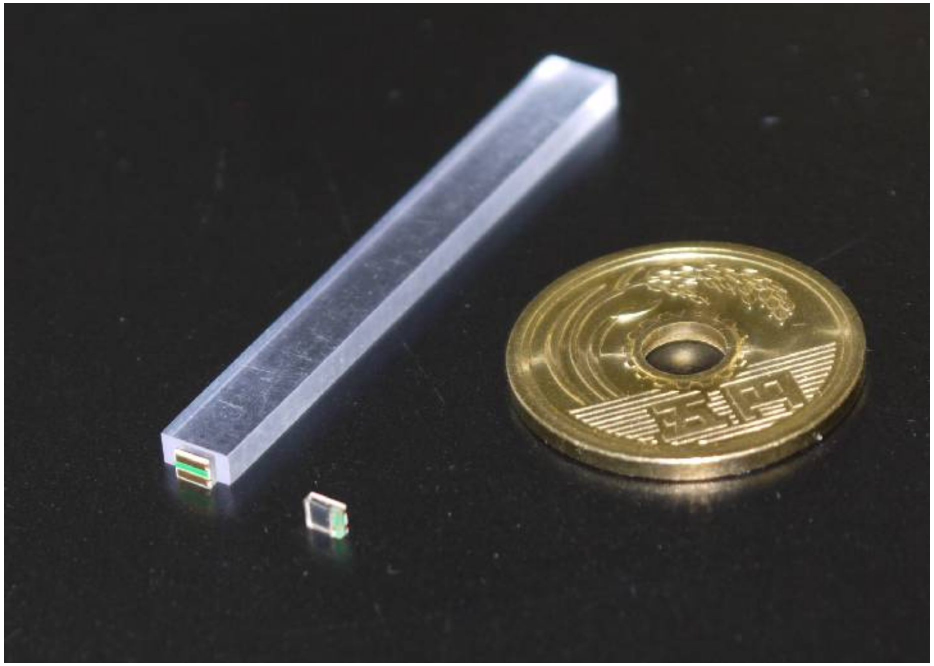


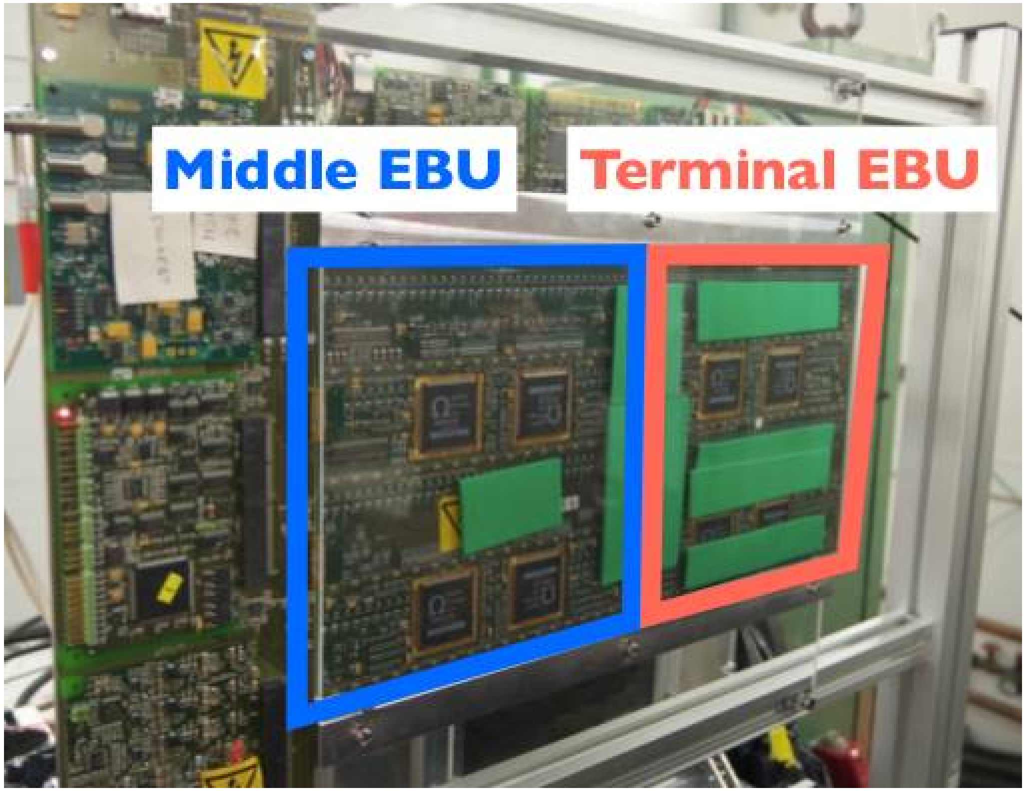


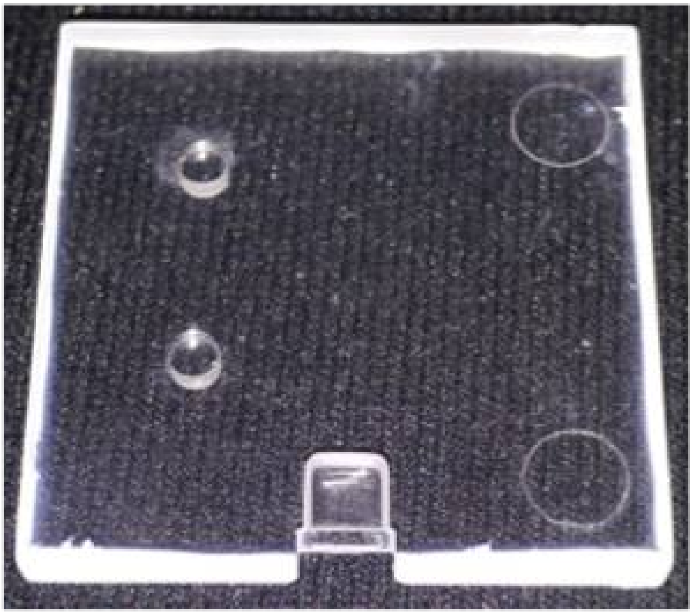
Si ECAL

technological prototypes

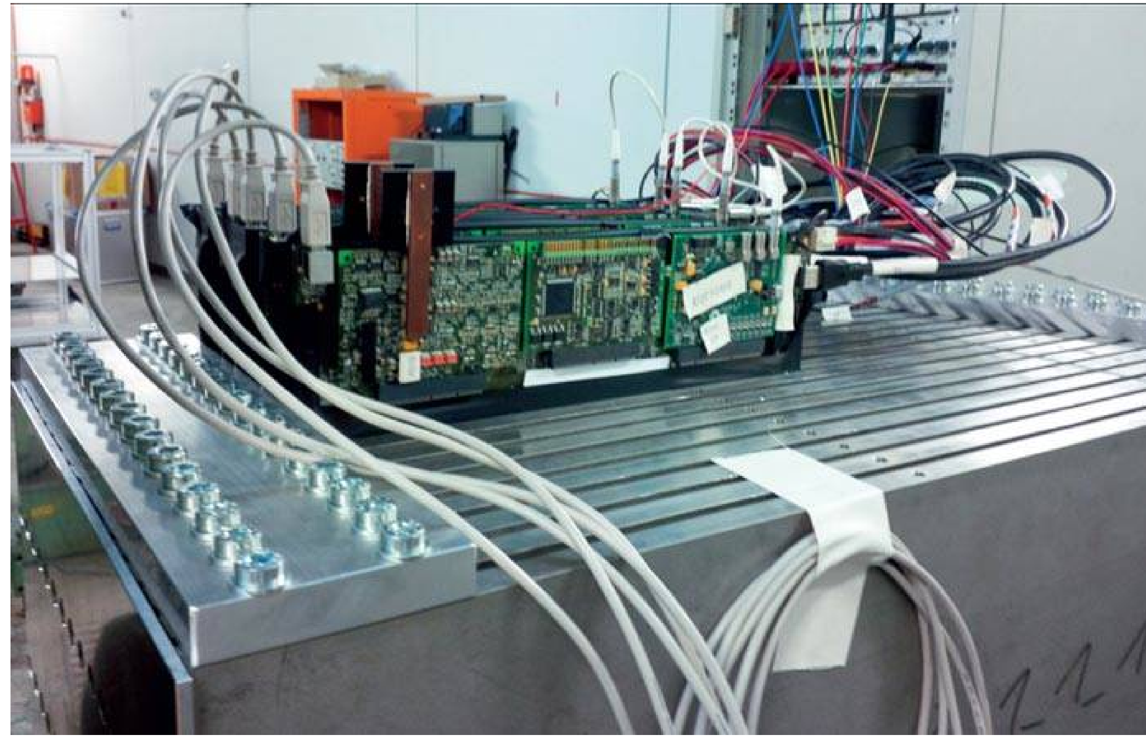
Sc ECAL



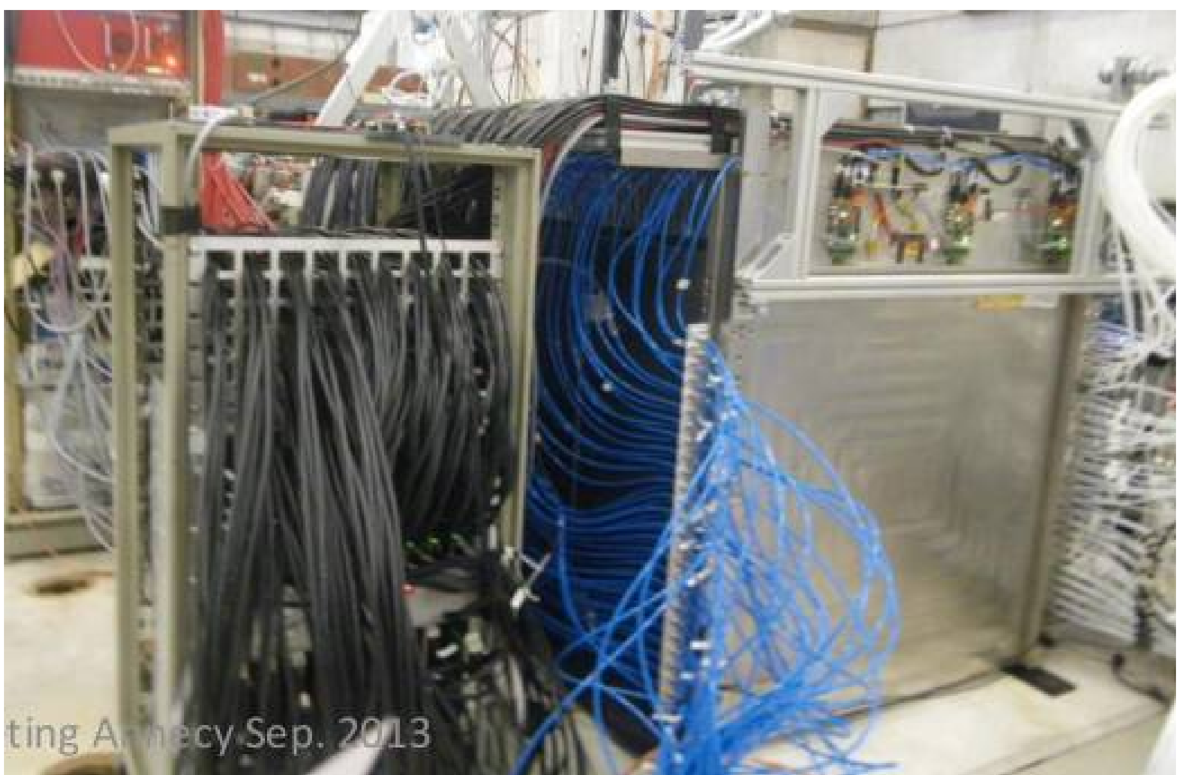




AHCAL tile



AHCAL



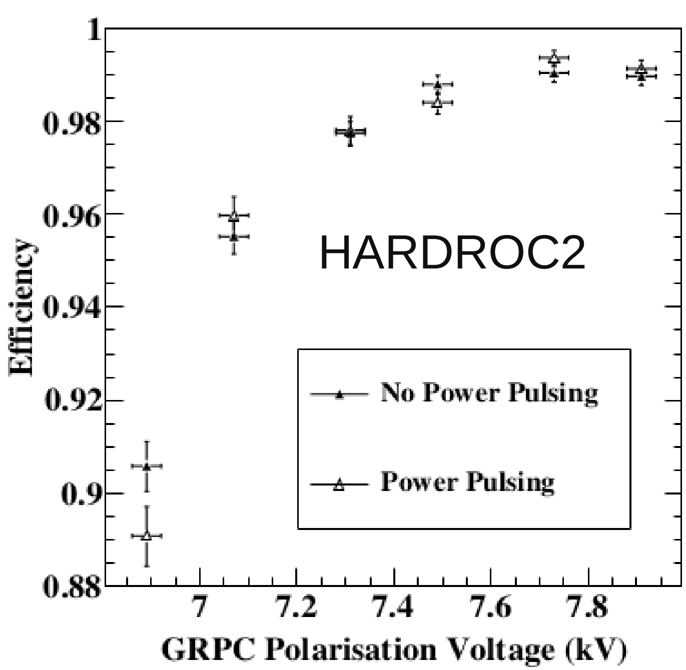
HCAL technical prototypes

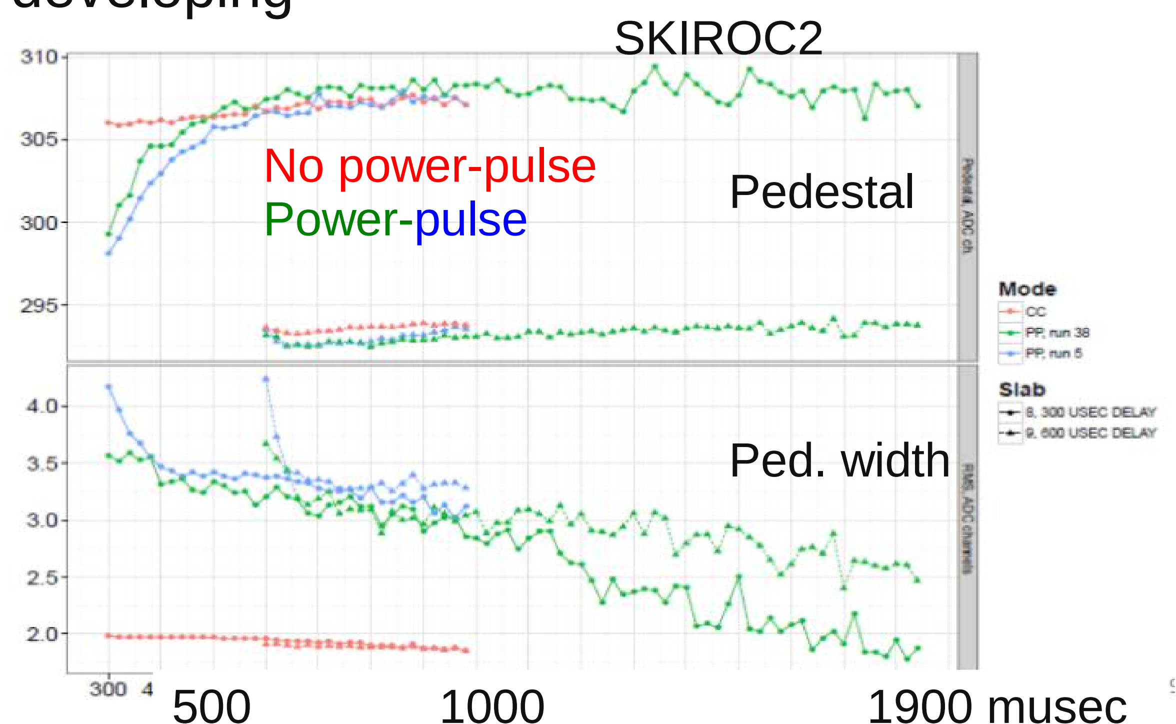
GRPC DHCAL

General status of sensors is good,
(functional, suitable for mass production)
e.g. guard-ring design of silicon sensors
scintillator tile and strip designs
SiPM/MPPC/etc developments
RPC

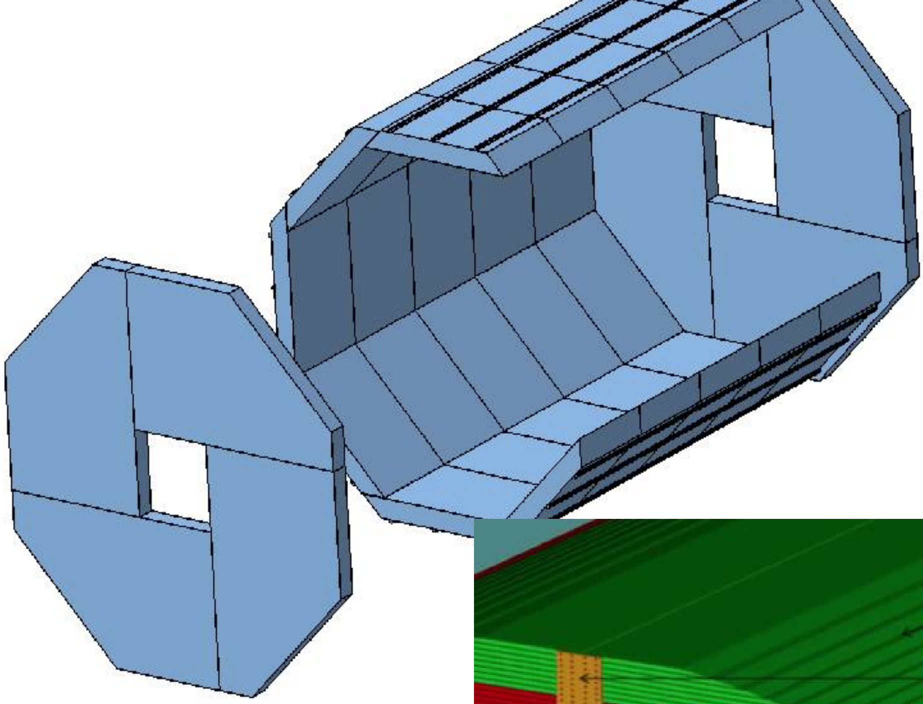
Front end electronics (all from *ROC family)
current generation being used for beam tests

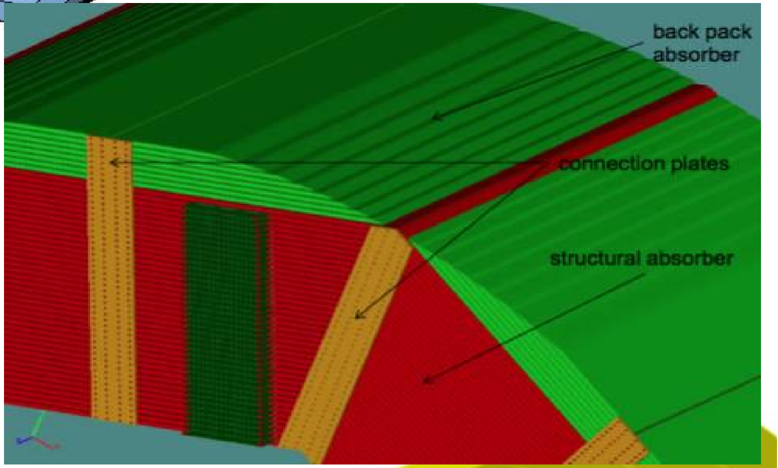
Several versions have (or are now) having their
power-pulsing capabilities tested
...understanding is developing

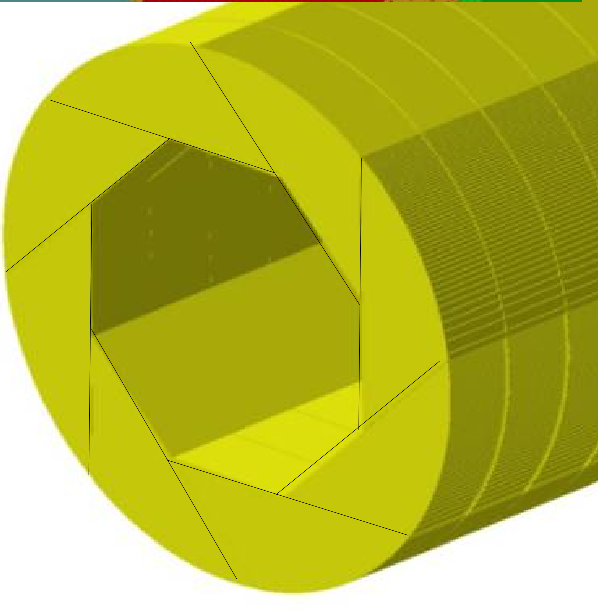




Mechanical structure
mostly barrel...







Common structure for ECAL
carbon-fibre, tungsten

~ 2/3 size module built

2 options for HCAL:
in principle independent of
readout technology

* TESLA
Relatively easy access to detector interface
electronics after installation

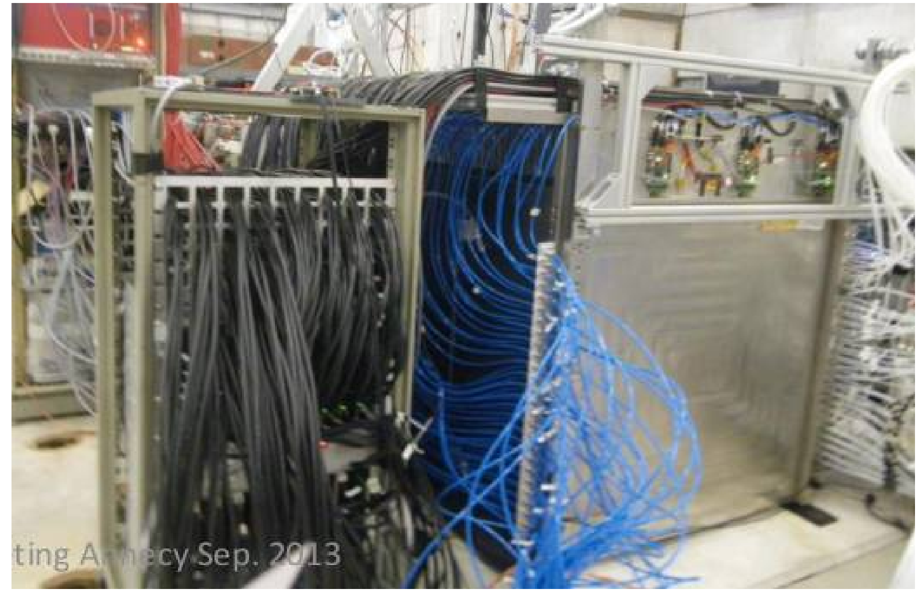
* “Videau” structure
better rigidity

Representative large-scale
mechanical prototypes produced

Access to detectors will be possible
only during long (> 1 year?) shutdowns

ILD-type scale mechanical prototype structures

ECAL



Videau-like HCAL

TESLA-like HCAL

PFA studies

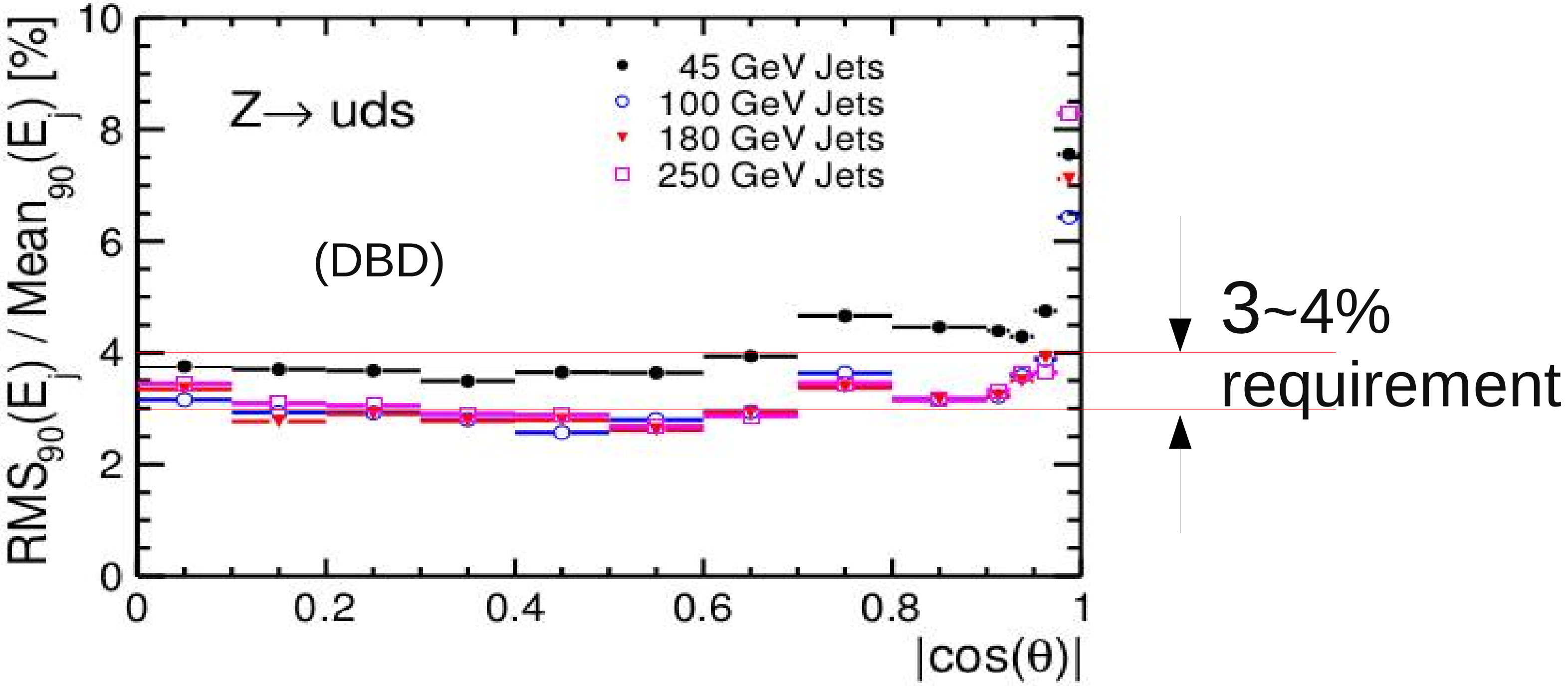
(in simulation) have shown that

required resolution can be achieved, and surpassed,
- with current detector designs

this performance is rather insensitive to
- technology
- simulation models (especially hadron shower models)

Software development has been done using
- Si-W ECAL and scintillator HCAL
- Optimisation of PF algorithms for
  - other technologies is underway

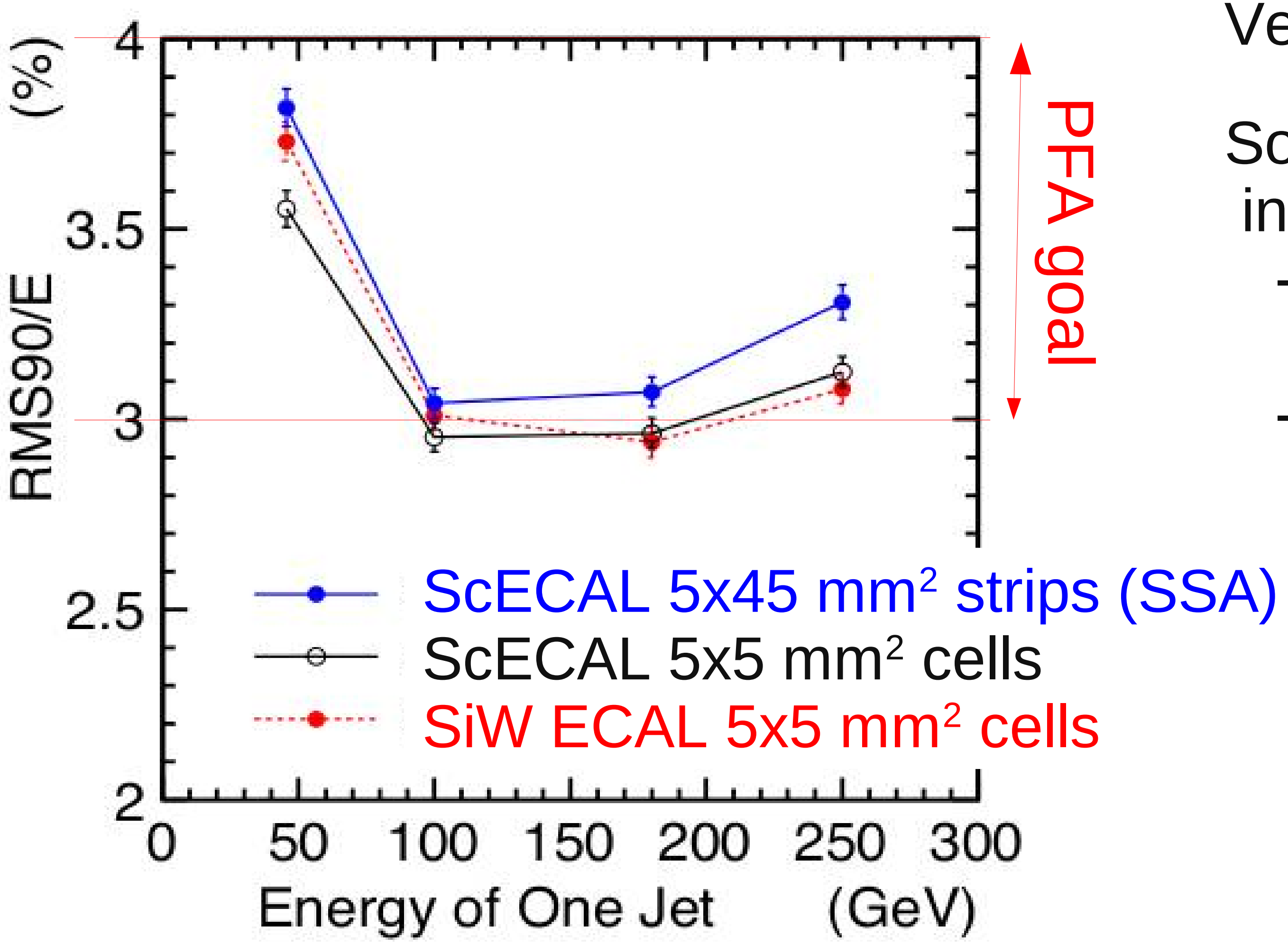
Pandora performance in ILD with SiW / AHCAL



Meets or exceeds minimum requirements in
(almost) all regions

What is limiting performance for forward jets
- Cables in overlap region?
- Software treatment of overlap region?
- TPC endplate (I suspect not...)
- ...

A lot of recent progress on Pandora calibration and Strip Splitting Algorithm for Scintillator ECAL



Very encouraging

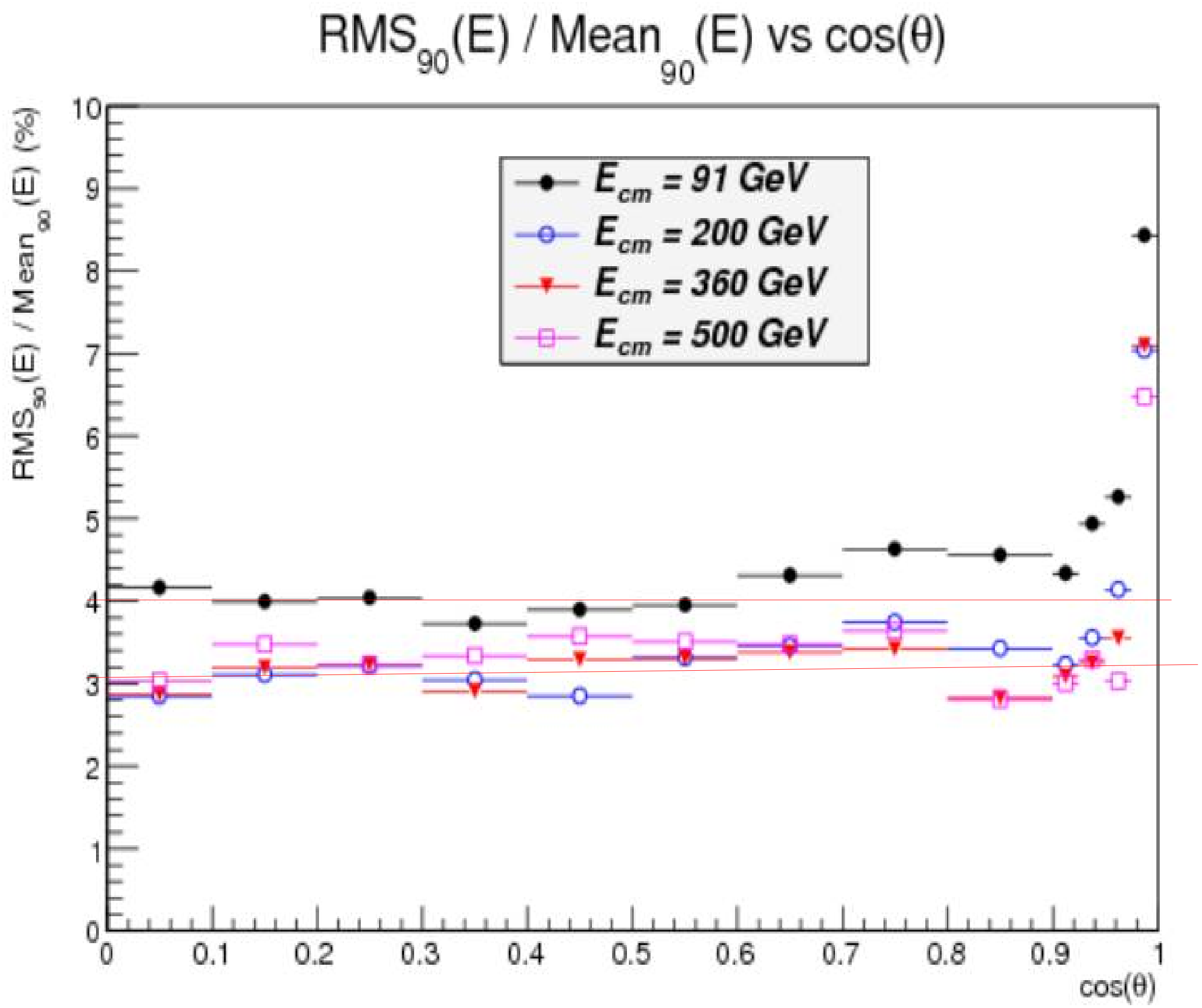
Some effects still to be included in simulation:

- Non-uniform strip response
- MPPC saturation

GRPC SDHCAL

A lot of work on simulation to match observed pad multiplicity

Pandora performance
with little tuning/calibration



(probably significant) improvements expected
with more involved tuning and calibration

CALICE program has demonstrated that:

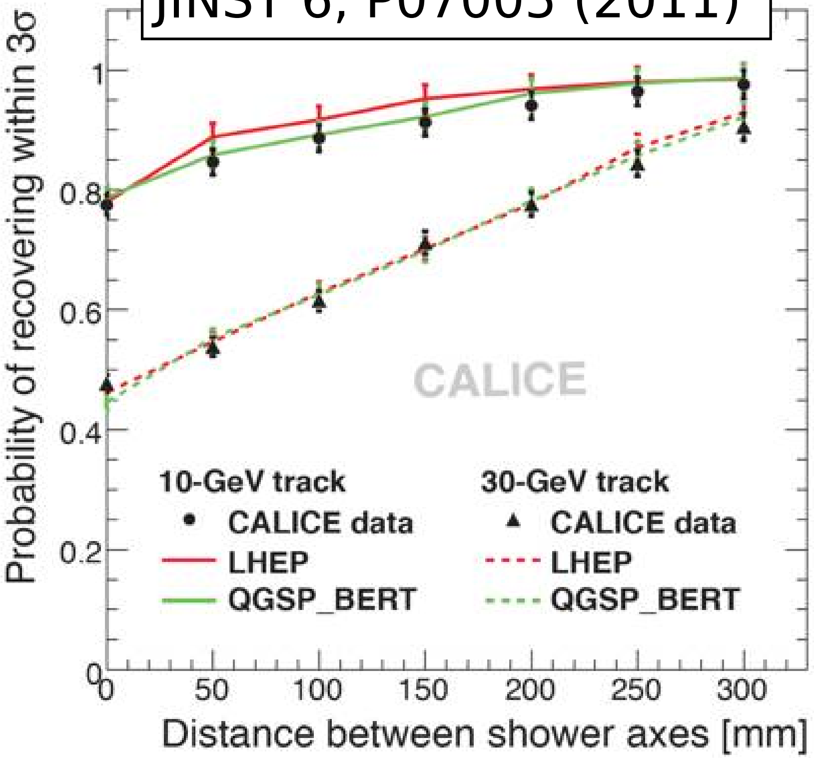
Large-scale, highly-granular calorimeters can be
designed,
built,
transported,
calibrated, and
operated stably for years

PFA performance can be well modeled in simulation
and is not very sensitive to
hadronisation model

Demonstrated in SiW/AHCAL
Data available for other technologies

-> confidence in ILD simulation results

JINST 6, P07005 (2011)



At this stage,

* development and testing of CALICE prototypes have
  not identified any show-stoppers on the construction,
  calibration, operation of any of the proposed technologies
    R&D progress consistent with detector TDR in a few years
      There is certainly work do be done on all fronts,
        but feasible with impetus & funding

* it seems likely that all these technological options
  can meet the performance requirements

On simulation side, further work on PFA optimised for SDHCAL
  expected to give significant gains
    but this needs to be demonstrated!

Tests of PFA particle separation comparing test beam and simulated data
  need to be repeated using ScECAL and SDHCAL
  in order that PFA simulation results can be trusted at
    same level of confidence

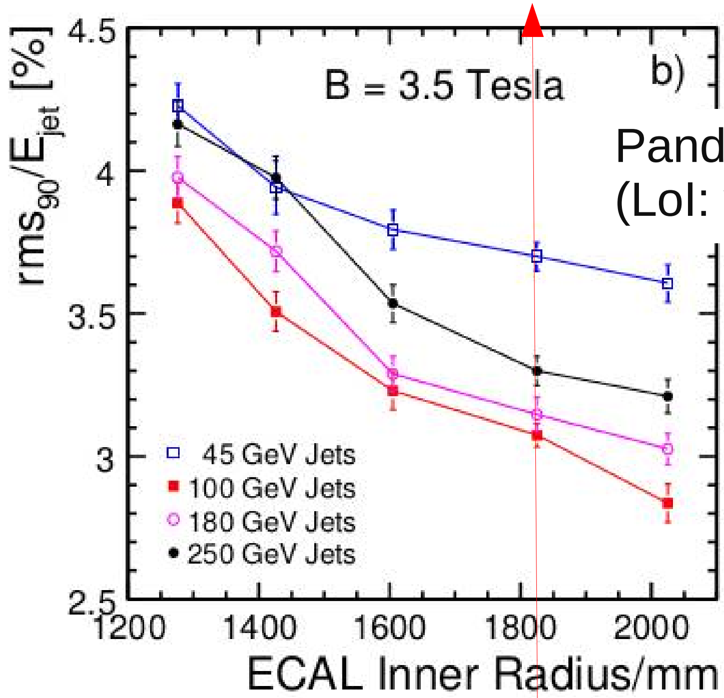
detector optimisation

clear that

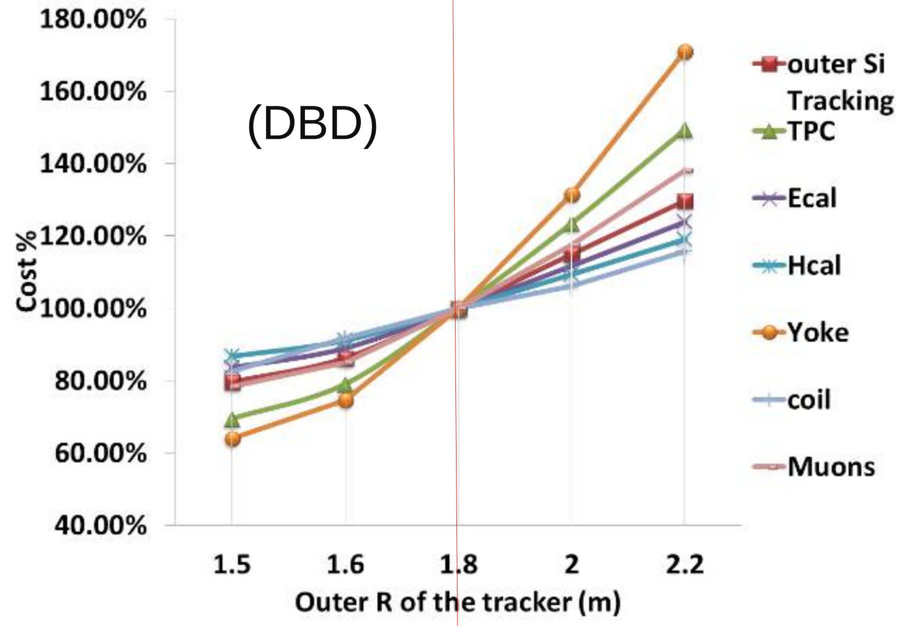
“bigger is better”

“smaller is cheaper”

ILD is now here



PandoraPFA
(LoI: worth repeating study)



Cost – performance optimisation

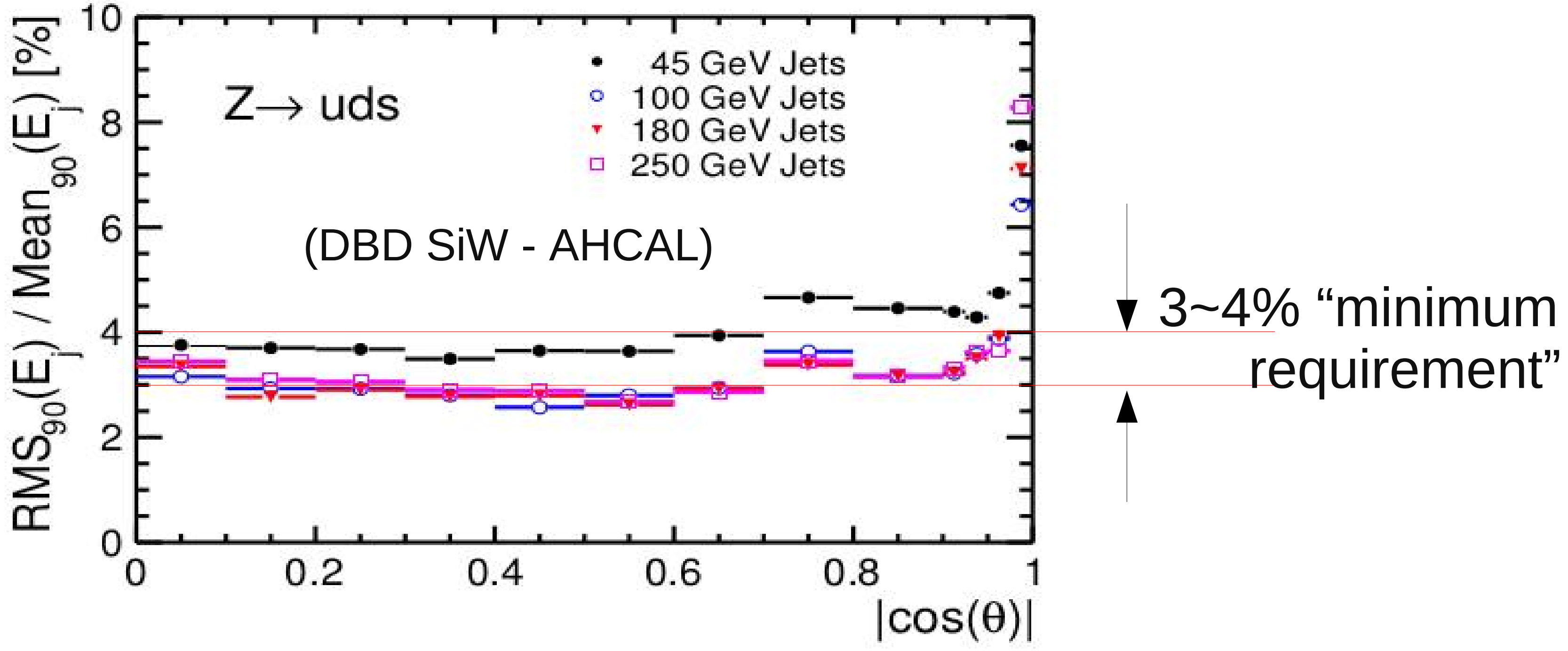
Important due to large calorimeter cost

Progress has been made on understanding and agreeing on the differences in cost between different technologies

from DBD:

- Sc-ECAL is ~1/2 cost of Si-ECAL
  - Hybrid ECAL design is between them
- difference between cost of HCAL options is negligible
- (probably some systematic uncertainties on these statements)

Cost – performance optimisation



We may be able to afford to degrade performance (and reduce cost)

particularly at at higher energies

although we should remember that this is simulation...

(naively)

Low jet energy performance ~ single particle resolution

High jet energy performance ~ detector size, segmentation

"Low energy" jets (~50GeV~m_{WZH}/2) are central to ILC physics

Suggests that detector size reduction may be more fruitful

than changes to detectors which degrade single particle resolution

Summary

Forward calorimetry

BeamCal and LumiCal are well developed

LHCAL rather forgotten...

Two well-established options for each of ECAL and HCAL, which

- deliver required physics performance
- are technically feasible and well proto-typed

further R&D certainly necessary on many fronts

Cost-performance optimisation

Various aspects to tune:

Overall detector size

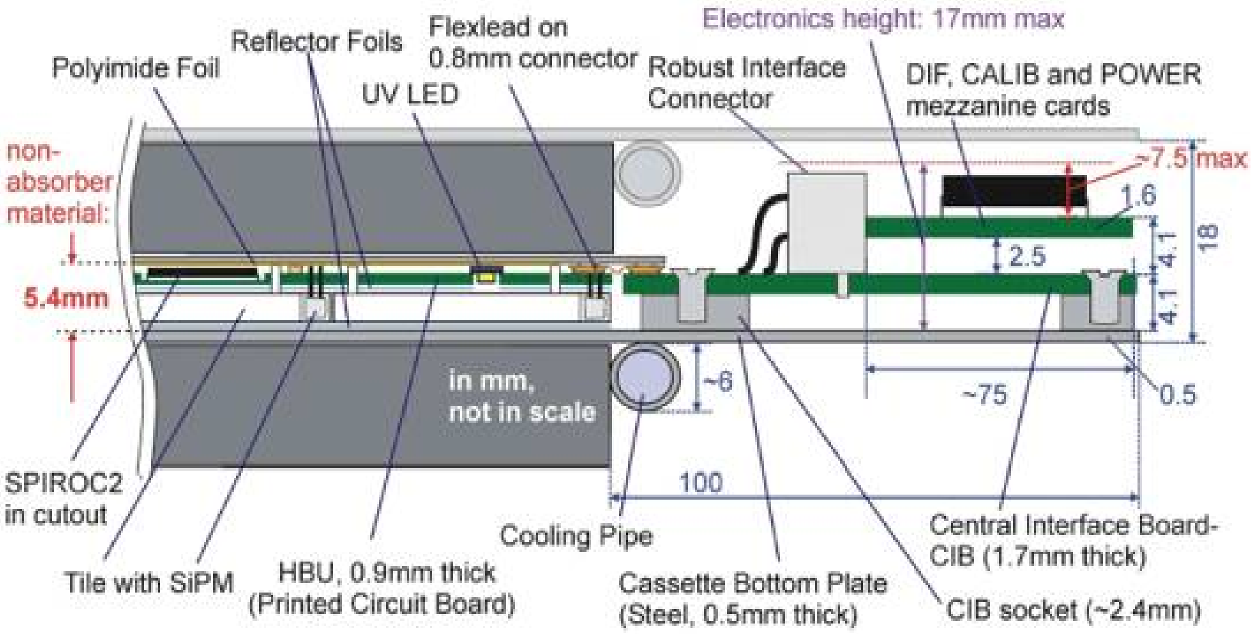
Detector design (e.g. # layers)

Detector technology (in ECAL)

backup

The Analog Hadronic Calorimeter

- Steel absorber structure - 2 cm per layer, ~ 48 layers (different geometries for absorber possible)
- 3 x 3 cm^2 scintillator tiles with SiPM readout - First used in large numbers by CALICE, by now a well-established technology all throughout HEP, medical imaging and beyond



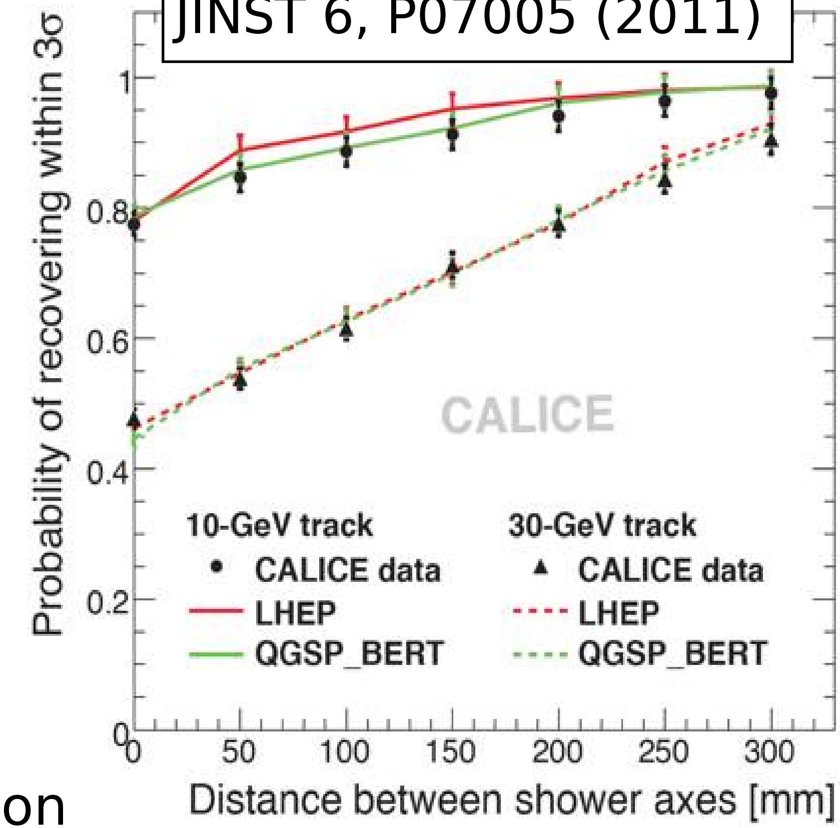
- Highly compact:
- < 6 mm non-absorber material per layer
- Fully integrated electronics with power-pulsing

Detailed simulation studies of PFA and physics performance with the AHCAL: Meets / exceeds ILD requirements over the full ILC energy range

Proven PFA Performance

- Calorimeter technology for ECAL & HCAL developed by CALICE: Combined test-beam experiments to demonstrate PFA calorimetry

JINST 6, P07005 (2011)



One highlight:
Shower separation with PandoraPFA in the SiW-ECAL and AHCAL physics prototypes
▸Good agreement with simulations demonstrates realism of ILD full detector simulations & physics studies

- In addition: Results on energy resolution and other performance parameters for all technologies

Technological prototypes either available or in construction

➪ We know imaging calorimeters work and can be built!

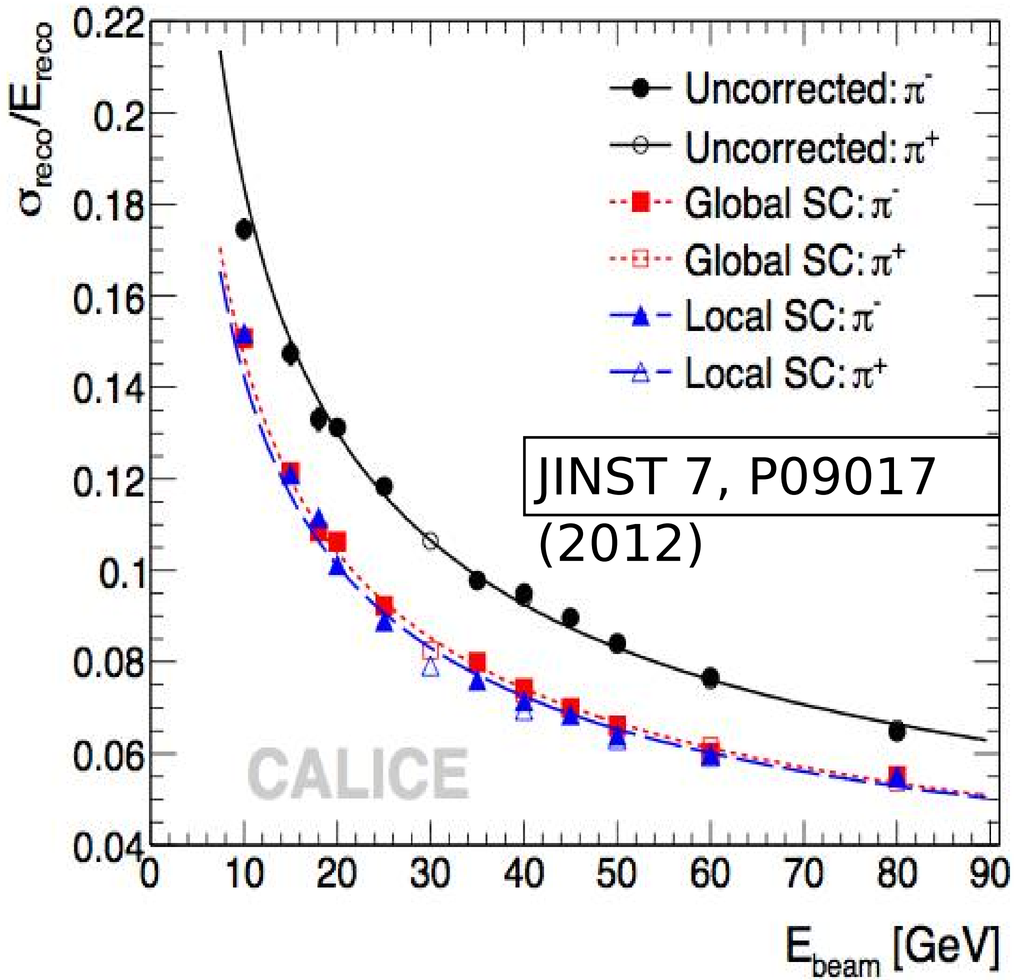
Frank Simon (fsimon@mpp.mpg.de)

Proven Detector Performance

- The AHCAL is not just a good PFA calorimeter, it is also an excellent stand-alone calorimeter - can compete with the performance of the best HCALs in currently running colliders

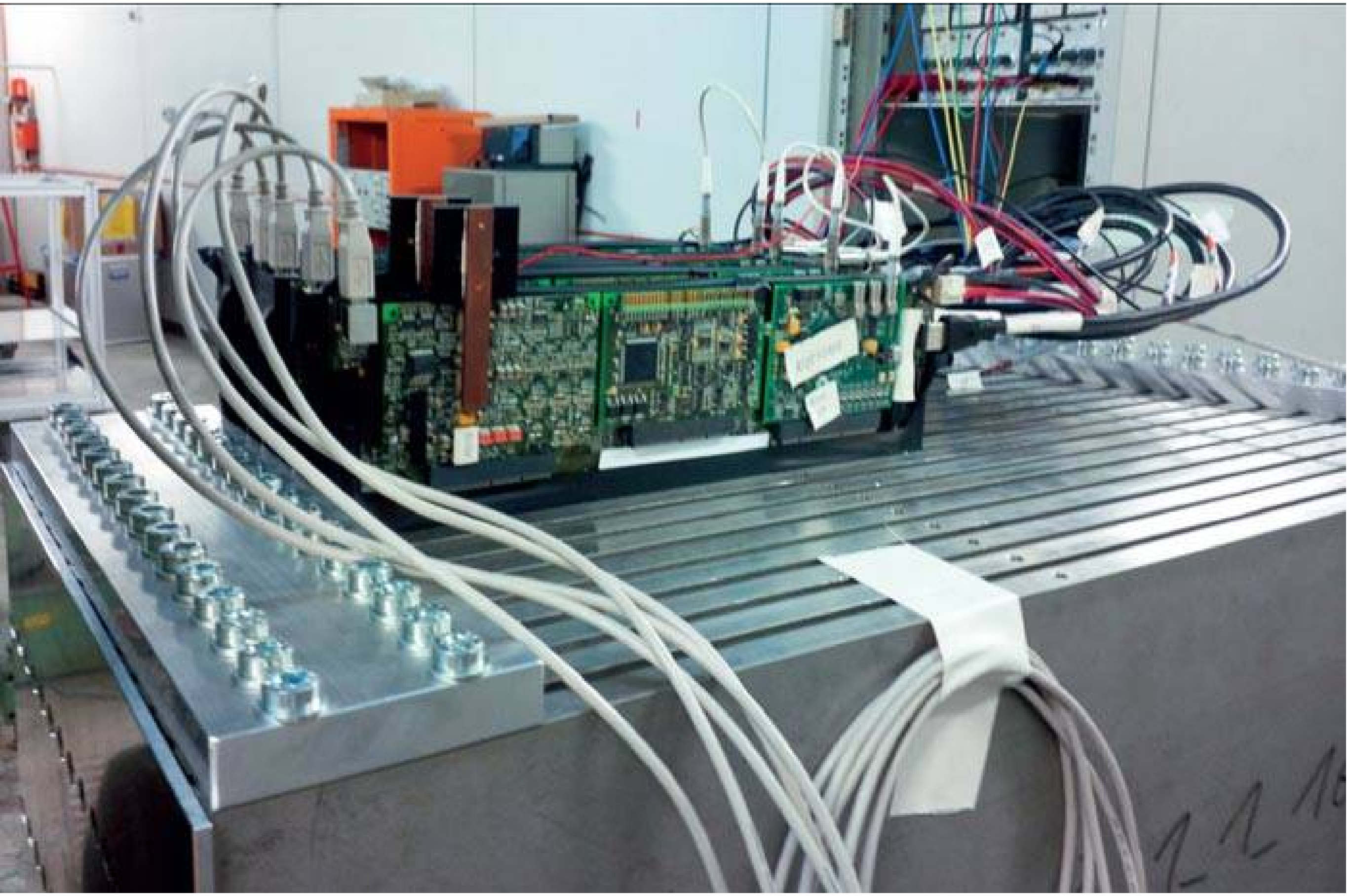
Full analog information provides linear response up to high single-particle energy

Hadronic energy resolution 45%/√E , 1.6% constant term with software compensation



JINST 7, P09017 (2012)

Preparing for a full Detector System



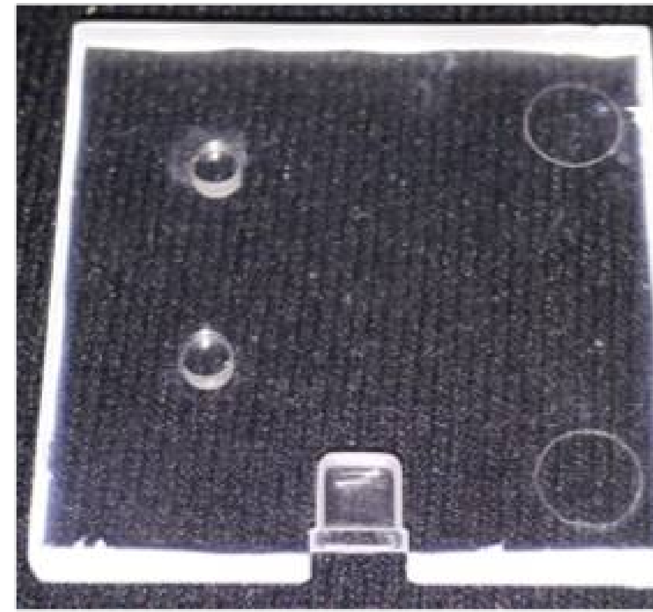
- First successful lab tests of five fully equipped HBUs in realistic ILD steel structure ("TESLA" geometry)

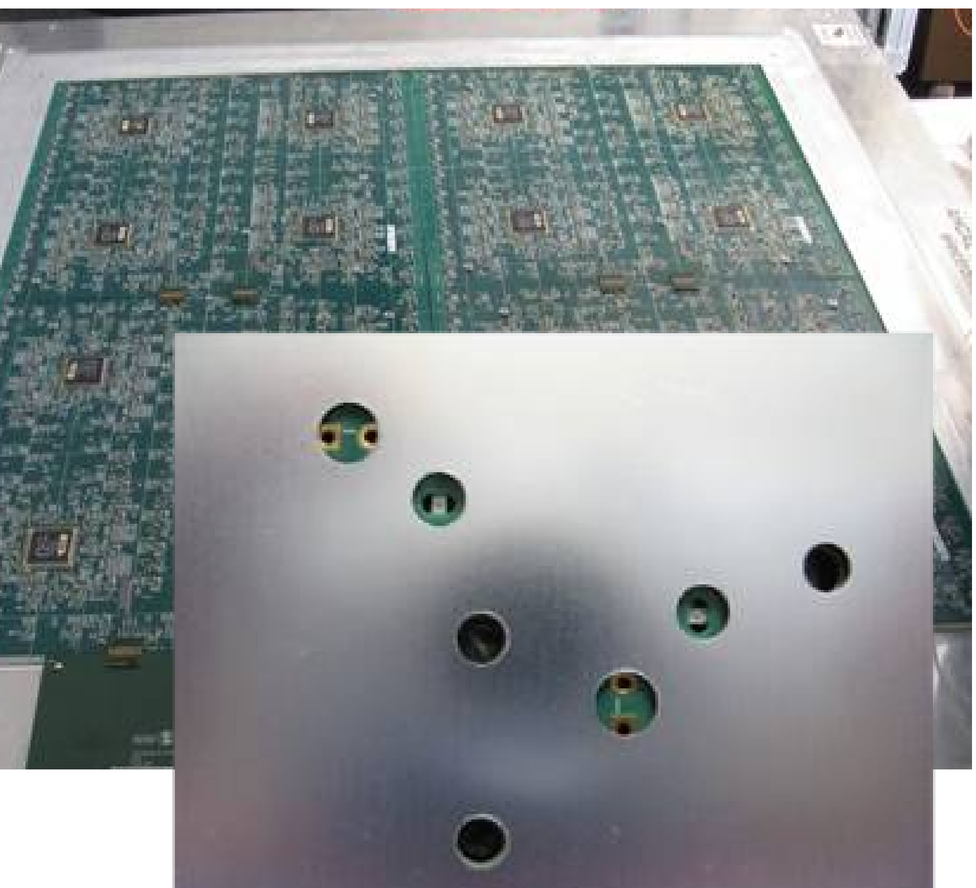
Ongoing R&D towards establishing the full mass production for key aspects of the system

Frank Simon (fsimon@mpp.mpg.de)

Preparing for a full Detector System

- Scintillator tiles suitable for mass production
  - direct coupling of SiPM, either on the side or on the bottom (will allow construction of “Megatiles”)





- Fully integrated electronics, with on-board LED-based calibration system
- Automated production of reflector foils by laser cutting proven
- Currently developing:
  - fully automated HBU assembly with pick-and-place robot and subsequent wave soldering
  - automated testing of large samples of scintillator tiles + SiPMs

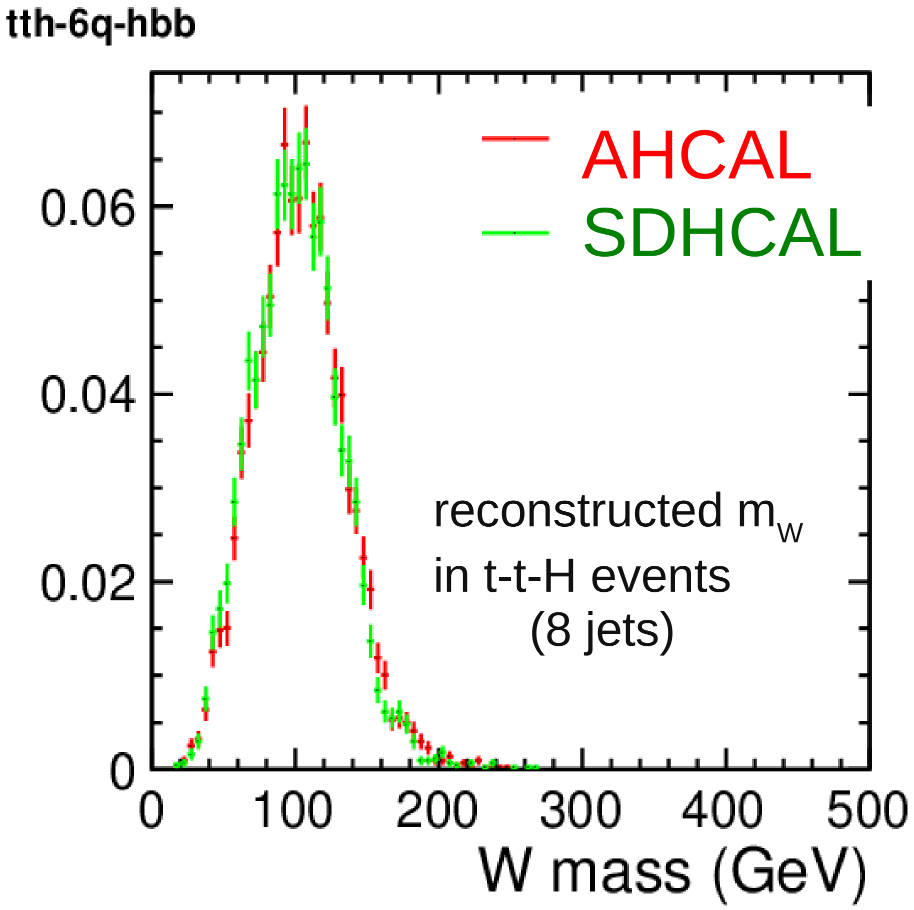
Jet resolution ($\cos\theta < 0.7$)

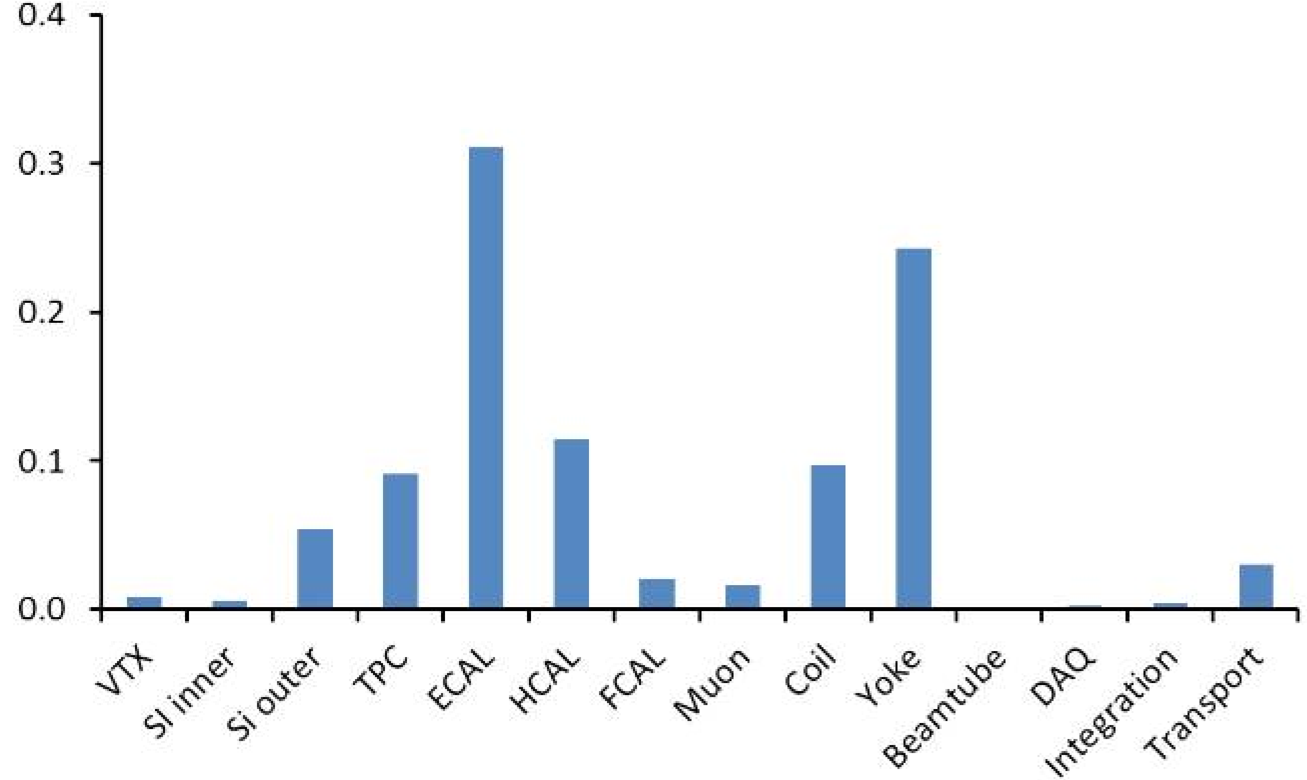
- ILD option 2 reconstruction using option 1 tuned PFA

E_j, GeV	SDHCAL, σ_{Ej}/E_j	AHCAL, σ_{Ej}/E_j
45	4.0%	3.7%
100	3.1%	2.8%
180	3.2%	2.8%
250	3.3%	2.9%

- AHCAL numbers from DBD,
- SDHCAL meets ILD goal with uncalibrated Pandora PFA

G. Grenier


tth-6q-hbb
0.06
0.04
0.02
0
0
100
200
300
400
500
W mass (GeV)
AHCAL
SDHCAL
reconstructed m_W
in t-t-H events
(8 jets)


0.4
0.3
0.2
0.1
0.0
VTX
SI inner
Si outer
TPC
ECAL
HCAL
FCAL
Muon
Coil
Yoke
Beamtube
DAQ
Integration
Transport